

Questions and Answers: Electrostatic Discharge

BY THE ESD ASSOCIATION

Explain the differences between the various models used to describe the ways in which electrostatic discharge can damage an electronic device.

Understanding how ESD damages a device is essential to implementing an effective ESD control program. There are three primary models that represent the ways in which ESD can damage a sensitive device. These models are used to describe the ESD event itself and also to classify the ESD sensitivities of the devices.

Because human beings are a principal source of ESD, the *Human Body Model* (HBM) is the most commonly used model to describe an ESD event. It typically represents a discharge from the fingertip of a charged person to the device. This type of discharge can occur from the simple act of physically picking up a sensitive component.

The *Charged Device Model* (CDM) represents a discharge from rather than to the device. For example, a device may become charged when sliding down a feeder. When the charged device then contacts a conductive surface, such as an insertion head, a rapid discharge occurs from the device to the conductive object. This type of event can be more destructive than the HBM event for some devices. Although the duration of the discharge is very short – often less than one nanosecond – the peak current can reach several tens of amperes.

The *Machine Model* (MM). This model is often described as a worst-case human body model event. However, the discharge in this event is represented as occurring from a conductive object to the component rather than from the human body. The object could be a hand tool, a pair of tweezers, or production equipment.

For additional information on these various failure models, consult the following resources:

Renninger, R. G., "Mechanisms of Charged Device Electrostatic Discharges," *EOS/ESD Symposium Proceedings, 1991*.

Avery, L. R., "Charged Device Model Testing: Trying to Duplicate Reality," *EOS/ESD Symposium Proceedings, 1987*.

Avery, L. R., "Beyond MIL HBM Testing - How to Evaluate the Real Capability of Protection Structures," *EOS/ESD Symposium Proceedings, 1991*.

ANSI EOS/ESD S5.1-1993 Revised – *Electrostatic Discharge Sensitivity Testing - Human Body Model*.

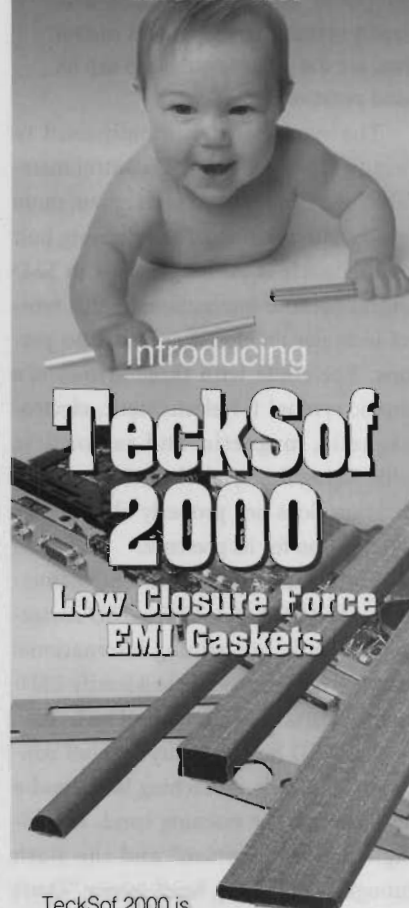
ANSI EOS/ESD S5.2-1994 *Electrostatic Discharge Sensitivity Testing - Machine Model*.

EOS/ESD DS5.3-1993 – *Electrostatic Discharge Sensitivity Testing - Charged Device Model*.

ESD ADV-2.0-1994 – *ESD Handbook*.

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We need to label parts as being ESD sensitive (ESDS). We also need a means to identify materials used for ESD control. What are the proper symbols to use for these purposes?

The symbols traditionally used to identify ESDS parts or ESD control materials have been replaced with newer, more appropriate symbols. The lightning bolt inside a circle is no longer used in ESD control because internationally this symbol indicates an electrical hazard to persons. The circle with three arrows is a generic symbol for electrostatic, electromagnetic, magnetic, and radioactive fields. Using this symbol for ESD control purposes does not properly alert people to the reason for its presence.

The symbols defined in ESD Association ANSI/ESD S8.1-1993 – ESD Awareness Symbols, are gaining international acceptance as the means to identify ESD-sensitive parts and ESD control materials.

The ESD Susceptibility Symbol consists of a triangle, a reaching hand, and a slash through the reaching hand. The triangle means "caution" and the slash through the reaching hand means "Don't



Figure 1: ESD Susceptibility Symbol

touch." Because of its broad usage, the hand in the triangle has become associated with ESD and the symbol literally translates to "ESD sensitive item, don't touch."

The ESD Susceptibility Symbol is applied directly to integrated circuits,



Figure 2: ESD Protective Symbol

boards, and assemblies that are static sensitive. It may also be applied to packaging materials to indicate that the contents are ESD sensitive. If desired, the sensitivity level of the item may be added to the label.

The ESD Protective Symbol (Figure 2), consists of the reaching hand in the triangle. An arc around the triangle replaces the slash. This "umbrella" means protection and indicates ESD protective material. It is applied to mats, chairs, wrist straps, garments, packaging, and other items that provide ESD protection. It also may be used on equipment such as hand tools, conveyor belts, or automated handlers that are especially designed or modified to provide ESD control.

Neither symbol is applied to ESD test equipment, footwear checkers, wrist strap testers, resistance or resistivity meters or similar items used for ESD purposes which do not provide actual protection.

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WORK HARD.

ESD In the Sky: Keeping Static Grounded

BY STAN ABRAMS

Editor, Compliance Engineering

TWA 800 wouldn't have happened if the spark or ignition source was prevented. But can you ever prevent sparks? No.¹

Despite the fact that anyone who has ever been zapped on a light fixture or door-knob during a dry winter's day has experienced electrostatic discharge, the term has until recently been unfamiliar to the majority of people. The tragic circumstances surrounding Trans-World Airlines Flight 800 and the subsequent demand for an explanation have thrust many heretofore unknown concepts into the public forum, one of which is static discharge. Sources of static electricity that can have a negative impact on aircraft systems include triboelectricity, engine exhaust ionization, precipitation charging, and close proximity to a thunderstorm. Although an ESD event has the potential to cause failures in avionics and other aircraft systems, this article will use the TWA incident to focus on the interplay between static discharge and the current regulatory stance towards commercial aircraft fuel tank safety.

Facts Surrounding the TWA Flight 800 Crash

On July 17, 1996, TWA Flight 800 took off from John F. Kennedy International Airport in New York, headed for Paris. At approximately 8:31 in the evening, the Boeing 747-131 crashed into the water eight miles south of East Moriches, New York. All 230 passengers on the flight were killed in the crash. Investigators have determined that as the plane was climbing at 13,800 feet, an explosion in the center wing fuel tank (CWT) occurred and was responsible for the crash. Evidence has also shown that at the time of takeoff from JFK, the CWT contained somewhere between 300 to 600 pounds, or 50 to 100 gallons of fuel; the CWT of a Boeing 747-131 has a capacity of approximately 13,000 gallons.

The subsequent theories which have been generated by investigators, the media, and conspiracy theorists run the gamut from short circuits to missiles, but even though the complete structure of the aircraft has yet to be recovered, investigators from the National Transportation Safety Board (NTSB) are fairly certain of the major cause of the incident: the ignition of the remaining fuel in the CWT.

Specifically, investigators have focused on the fact that air con-

ditioners had been running for two hours while the plane was on the ground. NTSB officials believe that the heat generated from the air conditioner compressors elevated the temperature of the remaining fuel in the CWT to the point where explosive vapor was produced.²

Remaining Questions

Testifying on July 10 of this year before the House Aviation Subcommittee of the Committee on Transportation and Infrastructure regarding the TWA accident, NTSB Chairman Jim Hall described in detail the efforts of the largest, and by all accounts the most expensive, investigation ever conducted by the Safety Board. Although Chairman Hall was able to point to the CWT explosion as the definitive cause of the crash, he was unable to specify what the source of the ignition was. He did suggest six possible scenarios which the NTSB had not yet ruled out:

1. Center Tank Scavenge Pump – This piece of equipment seems to be on the list because it has not been recovered and, therefore, can not be ruled out as an ignition source.
2. Static Electricity – If a static charge had built up on an ungrounded component in the CWT (Chairman Hall cited Wiggins couplings or Adel clamps as possible suspects), a spark could have ignited the fuel or fuel vapor.³
3. Fuel Quantity Indicating System – A short circuit in a wire bundle outside the CWT could have led to either a heated or charged probe or compensator inside of the CWT, resulting in ignition from a spark or overheating.
4. Number 3 Fuel Tank Electrical Conduit – A spark in the fuel tank vent tubes could send flames through to the CWT.
5. Small Explosive Charge – Although the NTSB has ruled out a large device, such as a missile, the possibility of a small charge placed in the CWT to ignite the fuel/fuel vapors has not been ruled out.
6. High-Speed Particle Penetration – A meteorite or other fragment travelling at high speed could have penetrated the CWT and ignited the fuel.

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Other Incidents of ESD and Fuel Tank Explosions

Although static discharge has not been proven as the culprit in the TWA incident, the past record of commercial fuel tank explosions suggests that it is a leading candidate. In a list compiled by the Federal Aviation Administration (FAA) in April, 1997 of all non-combat fuel tank explosions known since 1959, static discharge was responsible for four out of fourteen commercial airline incidents. These four cases are illustrative of the varied nature of these static events:

1. In 1964, a 727's wing tank exploded while it was on the ground undergoing maintenance. Ironically, the crew may have been attempting to inert the tank by spraying the inside with a fire extinguisher; unfortunately, the cold CO₂ particles carried charge into the tank,

igniting the vapor and killing one individual.

2. In 1968, another 727 which was being refueled suffered minor damage to one wing when the refueling system caused charge to be built up on the fuel; combined with a high rate of flow and splashing, the charge was sufficient to ignite.
3. An incident similar to that in example two occurred in 1971, prompting changes in refueling equipment and procedures.
4. In other example of irony, a Beechjet 400 suffered minor damage in 1989 when a static discharge from polyurethane foam, which had been inserted into the tank to prevent explosions, ignited the fuel.

When Are Fuel Tanks Susceptible to Static-Induced Explosions?

Upon first impression, it might seem obvious that jet fuel and electricity simply do not mix and that every precaution

should be taken to keep the two separate or explosions will undoubtedly occur. However, the issue is slightly more complex than it appears. Before an explosion is possible, two things must happen: the first is an ignition source, an amount of energy sufficient to ignite the fuel/air mixture, and the second is the temperature of the fuel. This temperature must be between the lower explosive limit (LEL), and the upper explosive limit (UEL), resulting in a combustible mixture of fuel and air.⁴ Jet A fuel has a flash point of at least 100°F, perhaps even lower.⁵ The NTSB estimates that the fuel temperature in TWA Flight 800's CWT was about 115°F. It is therefore possible that the temperature in Flight 800's CWT was sufficiently high to make the tank vulnerable to an ignition source such as a spark.

Safety Measures

There are several options currently available to reduce the danger of a static



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ION SYSTEMS

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These were some of the options which were available at the time of the NTSB investigation into the TWA Flight 800 accident and the formulation of its proposal to the FAA.

Recommendations Of the NTSB

In December of 1996, the NTSB made several safety recommendations to the FAA regarding fuel tank explosion dangers. At the time, the investigation was six months old, but as we now know, it was not even halfway concluded. The decision by the NTSB begs the question of whether new rules were really needed. Is it possible that the NTSB felt compelled to act because of the tremendous attention which the TWA investigation had generated? While the answer to that question may be difficult to ascertain, the response by the FAA suggests that, based on a cost-

benefit analysis, at least some of the recommendations may not be feasible.

The Board's recommendations fall into two categories, physical modifications and operational procedures. Under the former, the Board suggested that:

"[S]ignificant consideration should be given to the development of airplane design modification, such as nitrogen-inerting systems and the addition of insulation between heat-generating equipment and fuel tanks. Appropriate modifications should apply to newly certificated [sic] airplanes and, where feasible, to existing airplanes."⁷

The other design modification proposed by the NTSB would: "Require modification of the CWT of B-747 airplanes and the fuel tanks of other airplanes that are located near heat sources to incorporate temperature probes and cockpit fuel tank temperature displays to permit deter-

mination of the fuel tank temperatures."⁸

The proposed operational procedure changes recommended by the NTSB include refueling the CWT before flight from cool ground tanks as well as proper monitoring of fuel temperature and levels.⁹ Additionally, B-747 flight handbooks would be amended to include current information on management of fuel temperature and levels.¹⁰

The Current Regulatory Position

The FAA responded to the NTSB's proposals on February 18, 1997. In a notice published in the Federal Register on April 3, 1997, the FAA invited industry to comment on the proposed changes. In addition to an extensive background on the TWA incident and a list of known fuel-tank explosions, the notice listed several questions that remained outstanding. These included the costs associated with:

- a commercial transport nitrogen-inerting system;
- installing fuel temperature indication systems within fuel tanks;
- eliminating the use of volatile jet fuels such as Jet B and JP-4;
- maintaining full fuel tanks for the sake of stabilizing temperatures;
- cooling fuel;
- insulating fuel tanks from heat sources (e.g., air conditioners);
- in-flight or ground-based fuel transfer systems from other tanks.

The FAA also questioned the practicality of moving away from the use of air conditioners in order to ensure that heat is not transferred from compressors to fuel tanks; the notice pointed out that an alternate source of cool air would be necessary to maintain passenger comfort while planes are on the ground.

Responding to the NTSB's suggestion regarding nitrogen-inerting systems, the FAA noted that although such systems had been used in military aircraft for over twenty-five years, using them in commercial aircraft presented special problems. The FAA pointed out that ground-based

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event triggering a fuel tank explosion. These can be categorized according to whether the safety measure focuses on the ignition source or the fuel/ullage. With respect to the former, procedures have been put in place to prevent the kinds of static-induced explosions referred to in several of the above four incidents. Because these incidents occurred during ground refueling, several safety measures deal with the nexus between refueling equipment, ground crews, and fuel tanks. This is representative of the FAA's "ignition-source" approach to fuel tank safety. The NTSB, responding to a statement made by the FAA in February of 1997 concerning fuel tank safety, summarized this approach: "The FAA states that the airworthiness standards of 14 CFR Part 25 assume that fuel vapor in the tank [ullage] is flammable and that current fuel tank design requirements dictate elimination of ignition sources."⁶

In addition to this ignition-source approach, several safety measures are available which focus on the fuel/ullage. One of these is nitrogen inerting, a process which has been available for over twenty-five years. The system involves either replacing the oxygen-rich fuel vapor with nitrogen or mixing the two, rendering the ullage inert. In the case of the Lockheed C-5 system, a ground-based supply of cryogenic nitrogen is pumped into the tank; on the other hand, some systems involve pumping gaseous or liquid nitrogen into the tank while the plane is in flight. A third approach is the McDonnell Douglas C-17 on-board Inert Gas-Generating System (OBIGGS) which bleeds air from the tanks, separates the oxygen from the nitrogen, and reintroduces the nitrogen into the ullage in flight as needed.

Another option is safety foam, a polyurethane material which is inserted into fuel tanks. Safety foam has been generally effective in protecting against ESD, as well as short circuits and other ignition sources. Although it was implicated in a static event in 1989, the record is not specific as to the exact sequence of events. The foam operates in several ways to forestall serious explosions. These include:

- Absorbing heat;
- Preventing sloshing of fuel;
- Preventing a significant amount of vapor to develop;
- Acting as a primitive airbag if explosion does occur by absorbing energy.

Unfortunately, foam has its drawbacks as well, including its weight penalty, the fact that it simply gets in the way of maintenance efforts, and the time and nuisance involved in installing and removing the material.

An additional area of safety may be referred to as fuel tank management and involves maintaining a safe fuel level and temperature. One precautionary measure is to keep the tanks filled with fuel, thus reducing the volume of ullage; unfortunately, this also ensures that planes will routinely carry full loads of flammable jet fuel. Another option is to refuel planes with cold fuel, diminishing the possibility that excessive heat will drive fuel temperatures past the LEL.

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ESD and Avionics

Most ESD professionals would feel right at home if asked to give static control advice to an aircraft manufacturer.

Modern avionics systems utilize the same digital electronics and computer technology found in most offices, albeit with different levels of power, software and display capabilities. The high speeds and large capacities of modern PCs have paved the way for integrated avionics systems, which will assimilate, analyze and display the information that pilots need in more efficient and user-friendly ways than ever before. Navigation, hydraulics, environmental control and other systems will be readily available to pilots as graphical displays, pull-down menus, or point-and-click icons. With all of these new electronic devices being installed in aircraft, the people in the clean suits, heel grounders, and wrist straps at component factories around the world will be doing their part to protect the public from aircraft accidents. Preventing today's latent defect can forestall tomorrow's near-miss, flight delay, or unscheduled landing.

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systems would only protect aircraft until such a time during flight that the fuel tanks had been substantially emptied from consumption or when the ullage had been exposed to warmer air, which occurs during descent. It should be noted, however, that the FAA did not specify how fuel temperatures at thirty or forty thousand feet could be elevated quickly from a typical descent pattern.

Commenting on on-board systems, the FAA admitted that although their safety record was impressive in protecting against fuel tank explosions of the TWA Flight 800 sort, "development and installation of such systems are expensive and may be impractical because of system weight and maintenance requirements in some airplanes."¹¹

The FAA did not officially dismiss any of the recommendations made by the NTSB, but the tone of the notice suggests that the agency did not appreciate the suggestion that it had failed to protect the American public from fuel tank explosions for many years despite the existence of safety technology. The notice called for comment from industry by July 1, 1997, and at the time this article was written, no further report had been filed by the FAA on the issue.

On the other hand, the NTSB did respond to the FAA on July 1, 1997 and had mixed comments. The Board was dissatisfied with the FAA's approach towards the elimination of ignition sources, stating that since that policy had not been 100% effective, further safety measures were definitely in order. The Board further stated that soliciting comment from industry on aircraft modifications was appropriate, but that the FAA could have acted on the Board's operational procedure changes without such industry comment since those recommendations would not involve significant costs or policy changes.

Conclusion

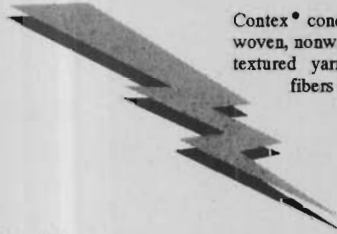
The conflict between the FAA and the NTSB on this issue is most likely a complex mix of politics, economics, honest disagreement and probably a host of other factors. One of the more interesting facets of the discussion, however, is the fundamental approach that each entity is taking towards the reduction of fuel tank explosions.

The FAA has tried to implement safety measures which protect against ignition sources. As the record shows, and as the NTSB points out, sources such as static electricity are extremely difficult to control and, to date, safety measures have not been completely effective. Whether the NTSB's recommendations are the solution or better static control is the answer, the awaited FAA decision will most likely bring static discharge issues once again into the discourse of popular opinion.

The TWA flight 800 incident has yet to be resolved and the specific cause has not been determined. As events unfold, *Compliance Engineering* will keep you updated in future issues.

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¹James Ott, "Methods to Protect Fuel Tanks Explored," *Aviation Week & Space Technology*, February 17, 1997, 67.

²Bernard Loeb, Director of Aviation Safety (NTSB), in interview with ABC News' Sam Donaldson, July 24, 1997.

³The contents of a partially-filled tank include the liquid fuel at the bottom and the fuel vapor in the space above. This vapor is referred to as the ullage.

⁴The FAA, citing *Marks' Standard Handbook for Mechanical Engineers*, Eighth Edition, maintains that "The lower and upper limits of flammability indicate the percentage of combustible gas in air below which and above which flame will not propagate. When a flame is initiated in mixtures having compositions within these limits, it will propagate and therefore the mixtures are flammable."

⁵Michael Dornheim, "Industry Seeking Single Response to NTSB Proposals," *Aviation Week and Space Technology*, July 14, 1997, 62.

⁶The NTSB issued its recommendations on December 13, 1996. The FAA responded on February 18, 1997. The NTSB issued a statement regarding the FAA response on July 1, 1997.

⁷National Transportation Safety Board Safety Recommendation A-96-174, December 31, 1996.

⁸National Transportation Safety Board Recommendation A-96-177.

⁹National Transportation Safety Board Recommendation A-96-175.

¹⁰National Transportation Safety Board Recommendation A-96-176.

¹¹*Federal Register*, vol. 62, no. 64 (April 3, 1997): 16019.